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ADVANCES IN HEAT TRANSFER ENHANCEMENT USING TWISTED TAPE INSERTS WITH AND WITHOUT NANOFLUID

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ABSTRACT

The phenomenon of heat transfer is employed in numerous applications such as refrigeration, air-conditioning, food processing, etc. Heat exchangers are used for efficient heat transfer and therefore, the performance of a heat exchanger is important. Cutting edge and cost-effective techniques are required to achieve efficient heat transfer. Twisted tape (TT) insert is one such technique. This article delivers an assessment on diverse types of TT with different nanofluids and without nanofluid. The influence of tape inserts on thermal performance factor (η), Nusselt Number (Nu), friction factor (f) and rate of heat transfer are comprehensively discussed. It is observed that, in general, TT increases Nu, f, η and heat transfer rate w r t plain tube. In addition, they are found to increase with enhancing tape length. The maximum values of these parameters are noted at full length of the inserts. Application of TT are demonstrated to be more useful in laminar than turbulent flows. On the contrary, when solid nano particles are employed with high value of volume fraction, heat transfer rate is better in turbulent than in laminar flows. It is observed that thermal performance factor is the cardinal parameter while choosing a TT configuration for a defined set-up.

KEYWORDS: Friction Factor, Heat Exchanger, Nanofluid, Thermal Performance Factor & Twisted Tape Insert

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Original Article

NOMENCLATURE

η	Performance evaluation factor	DR	Depth ratio
α	Attack angle	WR	Width ratio
α'	Wing inclination angle	PR	Pitch ratio
φ	Volume fraction	PI	Performance index
a	Perforated width	BR	Blockage ratio
f	Friction factor	TT	Twisted tape
h	Heat transfer coefficient	TR	Twist ratio
Re	Reynolds Number	ΔP	Pressure drop
Nu	Nusselt Number	WDR	Wing-depth ratio
T_c	Twist length	PWR	Perforated width ratio
W_T	Width of tape	BWR	Baffle width ratio
S_T	Axial spacing	BTR	Baffle twist ratio
D	Diameter of the inner tube	RRP	Relative rib pitch
L	Length of the tube	HDR	Hole-diameter ratio
N	Number of twisted tapes	PVA	Poly vinyl alcohol
d_e	Hydraulic diameter	CC-QTS	Counter current in quadruple counter tape in cross direction

1. INTRODUCTION

Heat transfer is an inevitable phenomenon and is employed in a wide variety of applications such as refrigeration, air-conditioning, thermal power plants, food processing, feedstock processing etc. In order to transfer the heat with lesser wastage and more efficiency, heat exchangers are used. The performance of a double pipe heat exchanger is vital vis-à-vis system economics and efficiency. Consequently, it is significant to improve heat transfer to acquire sustainable energy growth. A schematic of double pipe heat exchanger is shown in figure 1.

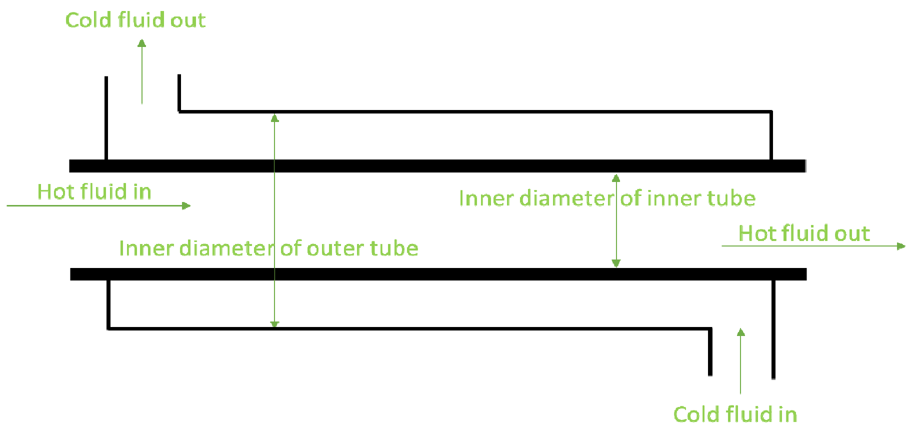


Figure 1: Schematic of Double Pipe Heat Exchanger.

Basically, there are three types of heat transfer enhancement pathways, namely, active method, passive method and compound method (Omidi et al., 2017). In active method, some external power or energy is supplied to improve heat transfer, such as induced pulsation by cams and reciprocating plungers, mechanical aids, fluid vibration, surface vibration, application of electrostatic fields, application of magnetic field to disturb the seeded light particles in a flow stream, etc. (Zhang et al., 2012). On the other hand, passive method employs geometrical or surface alterations in the flow channel. These modifications are carried out by inducing inserts or supplementary devices. Swirl flow devices, extended surfaces, treated surfaces, rough surfaces; coiled tubes, surface tension devices etc. are used in passive heat transfer enhancement pathway (Zhang et al., 2012, Saha and Saha, 2013, Anwari et al., 2014, Anwari et al., 2011). The combination of active and passive methods is called as compound method (e.g. rough surface with fluid vibration).

Passive method is the most popularly used method, as it employs no external power and enhance the heat transfer rate to a significant extent. Therefore, an optimal heat transfer rate is obtained at economical pumping power. Tube inserts technique is commonly used as one of the routes under passive method. Few examples of tube inserts in a heat exchanger are twisted tape, helical spring, ribs, conical nozzle, conical ring, etc. (Zhang et al., 2012, Saha and Saha, 2013, Anwari et al., 2014).

Among all the commonly used tube inserts, twisted tape insert is considered as a primary choice, and therefore extensively studied and researched by numerous researchers (Zhang et al., 2016, Zarringhalam and Karimipour, 2016, Yu et al., 2005, Yu et al., 2013, Yehia et al., 2016, Yang and Du, 2017, Wongcharee and Eiamsa-ard, 2011, Wadekar, 2017, Vashistha et al., 2016, Tuo and Hrnjak, 2013, Tu et al., 2016, Thianpong et al., 2009, Tamna et al., 2016, Suri et al., 2017, Sundar et al., 2016, Sun et al., 2016, Song et al., 2013) worldwide. A typical twisted tape is shown in figure 2. Although there are few review papers on passive heat transfer enhancement methods, there is no review focusing specifically on heat

transfer enhancement via twisted tape inserts and employment of nanofluids in the same. The investigations will be an aid to the future R&D in twisted tape inserts.

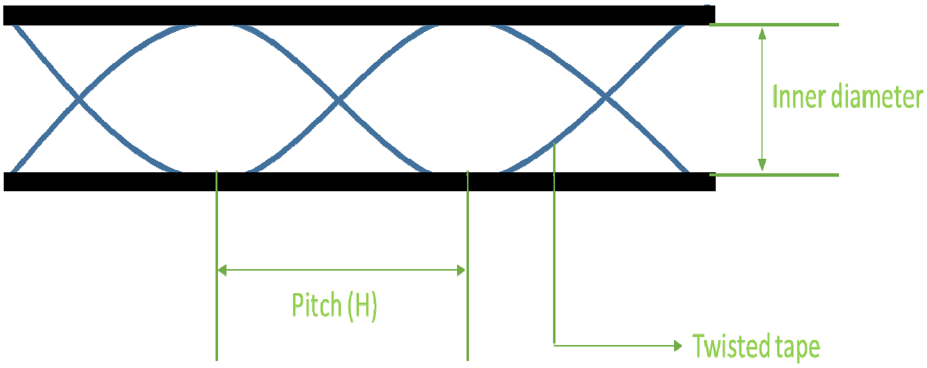


Figure 2: Structure of Typical Twisted Tape.

The goal of this review is to assess various twisted tape inserts used in previous work. In the next section, we discuss the main categories of twisted tape and the performance evaluation parameters. It also reflects the mechanism of heat transfer enhancement. Section 3 explains various experimental and numerical studies performed to investigate the heat transfer enhancement via different types of twisted tapes. Section 4 will include various experimental investigations carried out in the presence of nanofluid. This section will also shed light on the numerical work employing nanofluid. Discussion will be in section 5. The conclusions and recommendations will be discussed in the last section.

2. TWISTED TAPE INSERTS TECHNIQUE IN PASSIVE METHODS

2.1 Main Categories and Performance

Since 1960s, a vast number of theoretical and experimental studies are carried out to investigate the performance of a heat exchanger with wide variety of twisted tapes (Omidi et al., 2017). Twisted tapes can be manufactured in numerous designs such as typical, perforated, notched, jagged, center-cleared, V-cut, serrated, square cut, helical screw, etc. using different techniques as shown in table 1. Generally, polymer plastic, copper, steel or aluminum is employed in its formation. In order to discuss the features and performance of a twisted tape, it is desirable to understand some parameters related to the geometry and performance assessment.

- Twist Ratio- It is defined as the ratio of the distance between two points, which are on the same plane measured parallel to the axis of a twisted tape (i.e. half length of the twist pitch) to the inside diameter of the tube. It is usually denoted by TR or y.

  Numerically, $TR = H/D$

- Reynolds Number- It is the ratio of the product of tube side hydraulic diameter, mean fluid velocity of the tube and density to the dynamic viscosity of the fluid. It is denoted by Re.

  Numerically, $Re = d_e u \rho/\mu$

- Nusselt Number- It is denoted by Nu and is the ratio of the product of convective heat transfer coefficient and the tube side hydraulic diameter to the thermal conductivity.

  Numerically, $Nu = hd_e/\lambda$

- Friction Factor- It is the ratio of twice the product of pressure drop in the whole tube and tube side hydraulic diameter to the product of density, characteristic linear dimension and the square of mean fluid velocity of the tube. It is denoted by f.

  Numerically, $f = 2\Delta P d_e/\rho\mu^2 L$

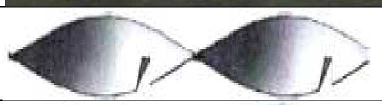
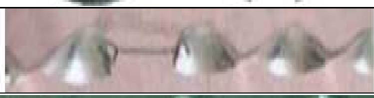
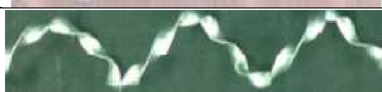
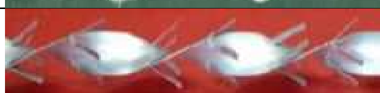
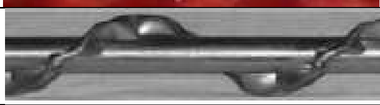
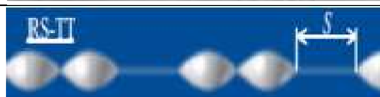
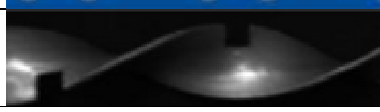
- Thermal Performance Factor- It is denoted by η and it is the ratio Nusselt Numbers (Nusselt Number of the tube with twisted tape to the Nusselt Number of the plain tube) to cube root of the friction factors (friction factor of the tube with twisted tape to the friction factor of the plain tube) under constant pumping power.

  Numerically, $\eta = (Nu_T/Nu_o)/(f_T/f_0)^{1/3}$

Where, H is the half length of twist pitch, D is the inside diameter of the tube, d_e is the tube side hydraulic diameter, u is the mean fluid velocity of the whole tube, ρ is the density of the fluid, μ is the dynamic viscosity of the fluid, h is the convective heat transfer coefficient, λ is the thermal conductivity, ΔP is the pressure drop in the whole tube and L is the characteristic linear dimension.

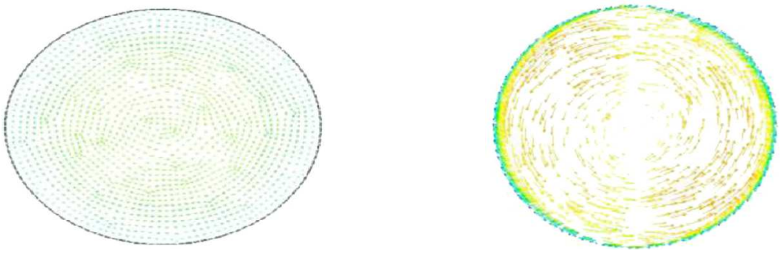
All these parameters are dimensionless in nature and are commonly employed to assess the performance of twisted tape in a double pipe heat exchanger. Among all the aforementioned parameters, thermal performance factor is most extensively used criteria. It is basically a trade-off between enhanced heat transfer and friction factor.

Table 1: Schematic Geometry of Different Configurations of Twisted Tape

Name	Configuration	Reference
Conventional TT		Mokkapati et al., 2014
Triangular groove TT		Zhenfei et al., 2012
Semicircular groove TT		Zhang et al., 2016
Regularly spaced TT		Zhang et al., 2016
Helical TT		Nanan et al., 2013
TT with V-winglet		Promvonge et al., 2014
Helical screw tape		Suhas et al., 2014
Regularly spaced TT		Eiamsa-ard et al., 2014
Square cut TT		Murugesan et al., 2010

2.2 Mechanism of Heat Transfer Enhancement

Analysis of heat transfer enhancement mechanism is carried out in this section, in order to understand better and develop an insight about twisted tape characteristics. Figure 3(a) and 3(b) show the velocity vector contour of a plain tube and a tube inserted with a twisted tape. It is clearly reflected in Figure 3(b) that the flow is helical in nature. In addition, the radial velocity and the cutting speed of the fluid flow near the wall are of better-quality vis-à-vis the tube without twisted tape insert. The mixing between the mainstream zone and the zone near to the wall is fast-tracked by the centrifugal force, which is induced by the tangential velocity (Zhang et al., 2016).



(a) (b)

Figure 3: Velocity Vector Contours (a) Plain Tube (b) Tube with Twisted Tape Inserts (Zhang et al., 2016).

The cardinal mechanism of the heat transfer improvement in a double pipe heat exchanger on account of twisted tape insert includes the decrease in hydraulic diameter of heat transfer tube, which in turn enhances the flow velocity and curvature. This causes an increase in the shear stress near the wall, and it is responsible for secondary motion. The thickness of the boundary layer is decreased as twisted tape blocks the path and enhances the velocity near the tube wall. The velocity is also enhanced, following the twisted tape due to the helical flow. The induced swirling flow as shown in Figure 4 is responsible for improved fluid mixing in the mid zone (area between the core and the near wall).

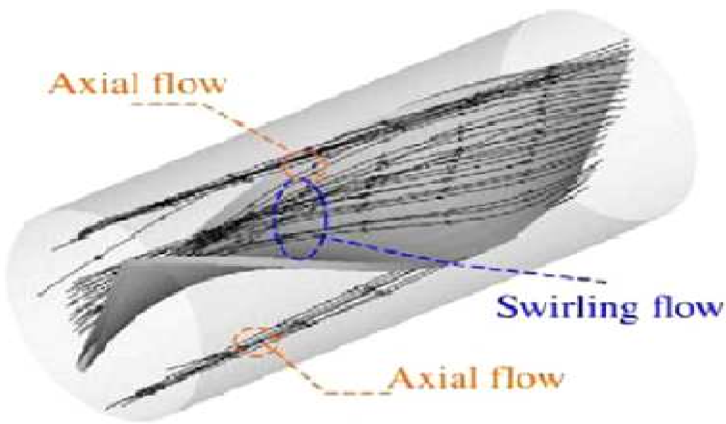


Figure 4: Swirl Flow in DPHE with Twisted Tape Inserts (Zhang et al., 2016).

It should be noted that heat transfer resistance mostly exists in the boundary layer, in a single phase fluid flow. The investigators should emphasize on achieving a higher convective heat transfer by decreasing the thickness of boundary layer. Twisted tape acts as a vortex generator which breaks the boundary layer and decreases the thickness of laminar bottom layer. Turbulence is induces by such inserts, which in turn induces superimposed vortex motion and consequently, a thinner boundary layer is achieved. This results in improved heat transfer coefficient.

3. IMPACT OF TWISTED TAPE INSERTS ON HEAT TRANSFER

Many researchers explored twisted tape inserts as a leading passive heat transfer enhancement technique. This section classifies twisted tapes in different types based on their design. Each subsection carries the major studies - experimental and numerical for the respective designs. Major studies along with the configurations, conditions and results of TT inserts with varying designs are summarized in table 2.

3.1 Effect of Rotating Twisted Tape

A large number of research works have been carried out to evaluate the antifouling, descaling and enhancement efficiency of rotating twisted tapes. The center of this type of tape rotates by itself whereas the tape is fixed with the rotating device on both the ends of the tube. A schematic of different types of tapes can be found in Table 1.

Lin and co-authors (Lin and Lin, 2007) evaluated the rotational speed of a twisted tape using experimental and numerical studies. They reported that the rotational speed was significantly impacted by the pitch of the twisted tape and axial speed of the flow. In other study (Wu, 2006) investigated the working attributes of self-rotating twisted tape and demonstrated an enhancement of 12 to 62% in the value of h. Zhang and co-workers (Zhang et al., 2007) worked and explored the heat transfer improvement mechanisms in rotating twisted tape inserts. The enhancement in velocity near tube wall and reduction impact of the equivalent diameter is the cardinal elements in heat transfer improvement at $TR \geq 10$. However, at $TR < 10$, helical flow effect is the major factor and at $TR \leq 1$, secondary recirculation was found to be the chief element. The impact of material of twisted tapes on heat transfer enhancement was also evaluated by some researchers (Zhang et al., 2016). They proved that the twisted tape inserts made of polypropylene have better overall performance, as compared to aluminum made twisted tapes.

Yu et al. (Yu et al., 2005) developed an experiment to evaluate rotating oblique teeth twisted tape using water as the working fluid. They reported that oblique teeth twisted tape were advantageous as they self-rotate on account of supplementary rotational moment generated by oblique teeth and enhance heat transfer even at low flow velocity (0.5 m/s). Peng et al. (De-qi, 2006) used straight strip insert with elliptical teeth and broken edge on both sides, to eliminate the difficulty faced in manufacturing twisted tape with elliptical teeth. It was demonstrated that this kind of insert can efficiently work at a flow speed of 0.5 m/s, the value of h was enhanced by 171%. In addition, Zhan (Zhenfei and Ruijuan, 2012) performed a study to assess the effect of triangular groove twisted tape inserts. The study was carried out on two different twist ratios of 5 and 7. They reported that the triangular groove disturbed the boundary layer, which in turn, enhanced the rotational speed and pressure drop. Furthermore, researchers also investigated the regularly spaced twisted tape and reported that these types of tapes have lower heat transfer and friction values vis-à-vis full length twisted tapes. They concluded that higher twist ratios have low impact on heat transfer and flow resistance attributes.

An undesirable phenomenon, known as fouling is observed on the tube walls in a heat exchanger. Higher energy consumption, loss in materials and lower production are few of the major outcomes of fouling. Scaling is another nuisance, which is basically a combination of particulate scaling and crystallization scaling. It is interesting to know that the rate of formation of crystallized salts on heat transfer tubes is very rapid (for e.g. the layer formed can grow up to few mm within an hour).

Numerous investigators have worked on these problems and found some feasible solutions. In general, if the boundary layer is disturbed by employing a self-rotating twisted tape insert, descaling and anti-fouling can be achieved. A

torsional wave can be produced by the rotation of a twisted tape insert under specific flow conditions. The fouling is removed by the radial vibration generated when the edges of twisted tape strike. The inner fouling in the tube is removed by the circumferential shear stress produced by the rotary motion of the insert. In this way, it scrapes the existing fouling and prevents the formation of fouling, thus provide a neat surface for enhanced heat transfer.

Li et al. (Li and Xiang, 2008) performed studies to evaluate the thickness of crystallized salt and the values of h for both the cases, namely, with rotation and without rotation of a spiral. They reported that in a continuous production for long term, the thickness of crystallized salt was reduced from 5.4 to 2 mm and the rotation of the spiral did not wear the wall or caused any other damage. Zhang et al. (Zhang and Qian, 2006) did numerous experiments to assess adhesive velocity of fouling, dynamic thermal resistance of fouling and abrasion velocity of the tube wall. They evaluated these parameters for the smooth tubes and for the tubes with self-cleaning plastic twisted tapes. The results revealed that the average adhesive velocity of fouling for tubes with inserts were only 54% vis-à-vis smooth tubes. On the other hand, average dynamic thermal resistance of fouling in the tubes with inserts was 30% lesser than the tubes without inserts. Therefore, they concluded that tubes with rotating inserts are a better choice in heat exchangers vis-à-vis fouling issues. Yu et al. (Yu et al., 2005) performed two different studies to study the impact of oblique teeth twisted tape inserts on the phenomenon of fouling. They reported that the total moment of force was enhanced from 75 to 101% as compared to smooth twisted strip, which in turn increased heat transfer and reduced fouling. In their second study, they employed dissymmetrical oblique teeth dispersed evenly on both sides of the rotating strip. Amazingly, an increase of 277% and 22.8-30.7% were reported in the overall moment and the value of h, respectively.

3.2 Effect of Conventional Twisted Tape

Yadav (Yadav, 2009) assessed the impact of half-length twisted tapes on a U-bend double pipe heat exchanger, on heat transfer and pressure drop. A 40% increase in the heat transfer was reported with the inserts vis-à-vis without inserts. However, the performance evaluation criterion of a smooth tube was reported to be 1.3 to 1.5 times higher than the modified heat exchanger. Furthermore, Naphon (Nephon, 2006) carried out the experimental investigation on a double pipe heat exchanger with and without insert to assess the variation in heat transfer and pressure drop. The thickness of the inserts was 1 mm and made up of aluminum. Hot and cold water was employed as the working fluid. They reported a vital improvement in heat transfer and an increase in pressure drop in the heat exchanger with tape inserts as compared to without inserts.

Few researchers (Mwesigye et al., 2016) carried out numerical work to evaluate the performance of conventional twisted tape inserts in a heat exchanger. They employed finite volume method. The Reynolds number of the flow was from 10260 to 1353000. The twist ratios were taken from 0.5 to 2 whereas width ratio was taken from 0.53 to 0.91. The results reported an increase of about 169% in heat transfer, a decrease in absorber’s tube circumferential temperature difference up to 68% and an enhancement in thermal η up to 10% over a receiver within a plain absorber tube. In addition, they reported an optimal Re to have a direct relation with twist ratio and inverse relation with width ratio. They also found maximum decrease in entropy generation rate to be 58%

3.3 Effect of Twisted Tape with Variable Length, Alternate Axes and, with Fins and Winglet

In order to satisfy some operating conditions and to enhance the rate of heat transfer, various designs in twisted tapes were manufactured and tested experimentally and numerically. Short length tapes with different pitches or tapes with alternate

axes or tapes with fins and winglets were evaluated by numerous researchers (Wongcharee and Eiamsa-ard, 2011., Wongcharee and Eiamsa-ard, 2011., Thianpong et al, 2012., Promvonge et al, 2014., Eiamsa-ard et al, 2010., Maddah et al, 2014., Jaisankar et al, 2009).

A thermo syphon solar water heater with left right twist was assessed to evaluate heat transfer and friction factor characteristics by Jaisankar et al. [(Jaisankar et al., 2009). They employed a twist fitted with rod and spacer at the trailing edge for varying lengths (100, 200 and 300 mm) for the twist ratio. As far as heat transfer was concerned, full length twist was found to be better than the twist fitted with rod and spacer. Twist fitted with rod has 18% and twist with spacer has 29% lesser values respectively for the friction factor. Eiasma-ard and co-authors (Eiamsa-ard et al., 2013) did a comparative study to evaluate uniform (UT) and non-uniform (NUT) alternate lengths tapes with conventional twisted tape. They reported a better heat transfer rate in UT and NUT on account of improved fluid mixing vis-à-vis conventional tape. Numerical outcomes demonstrated that temperature distributions were non-uniform in case of plain tape as compared to UT. The values of Nu and f were higher in case of UT and NUT and were found to be in inverse relation with alternate length. Furthermore, in NUT, heat transfer and friction factor characteristics were reported to rely upon alternate length rather than the variation of length.

Few researchers also investigated the impact of additional units such as fins, winglets, etc. on the heat transfer characteristics of conventional twisted tape. Promvonge et al. (Promvonge et al., 2014) studied the influence of twisted tape with rectangular winglet on heat transfer and pressure drop for the fluid flow with Reynolds Number between 4000 and 30000. The values of Nu and f were noted to have a direct relation with winglet to duct height ratios whereas they were in inverse relation with winglet pitch to tape width ratios. In addition, an improvement of 17% was reported in the thermal performance while using combined vortex flow devices as compared to individual twisted tape.

3.4 Effect of Multi Twisted Tape and Twisted Tape with Slots, Holes and Cuts

In order to enhance the rate of heat transfer, some researchers carried out studies with more than one twisted tape inserts inside the tube of a heat exchanger. In general, multiple twisted tape inserts inside the tube induces a strong vortex motion, which in turn improve the heat transfer characteristics. Moreover, change in geometry in the inserts such as slots, holes, cuts, etc. were found to induce strong turbulence near the tube wall, which in turn enhances heat transfer and decreases pressure drop. Different researchers studied different geometries viz. experimentally and numerically, using tape inserts.

Hong et al. (Hong et al., 2012) developed a CFD model of converging-diverging (CD) tubes with multiple twisted tape inserts inside them to develop the insights regarding thermo-physical behavior of fluid flow inside the tube. Results demonstrated that at constant pumping power, both CD and CDT reflected improved thermal performance than the plain tube. In addition, an enhancement in Nu and f were reported for CDT as 6.3-35.7% and 1.75-5.3%, respectively vis-à-vis CD. Bhuiya et al. (Bhuiya et al., 2013) carried out experimental work to assess the thermal performance, heat transfer rate and friction factor for a tube with three tape inserts. It was noted that Nu, f and η have an inverse relation with twist ratio Nu and F were found to improve 3.85 and 4.2 times respectively, vis-à-vis tube without tripe inserts.

Eiasma et al. (Eiamsa-ard and Promvonge, 2010) assessed heat transfer and pressure characteristics for serrated edge twisted tape insert. They reported that Nu enhances with the increase in depth ratio, but reduces with the width ratio. Moreover, the heat transfer rate was found to be 72.2 and 27% respectively, higher as compared to plain tube and conventional insert. Circular tube fitted with rectangular cut tape insert was investigated by Salam and co-workers (Salam

et al., 2013) to evaluate h, f and η. They demonstrated that Nu, f and η enhanced respectively 2.3-2.9 times, 1.4-1.8 times and 1.9-2.3 times vis-à-vis smooth tube.

3.5 Effect of Helical and Screw and Center-cleared Twisted Tape

Helical and screw type twisted tape inserts and center-cleared inserts are considered as an advanced version of twisted tape inserts. Various investigations were performed to examine thermo-hydraulic performances of these tapes. A square duct fitted with helical screw tape with variable twist ratios was experimentally evaluated by Patil et al. (Suhas and Vijay, 2014) to assess heat transfer rate and friction factor. The values of Nu was found to have a direct relation with Re and inverse relation with TR. The values of Nu and f were noted to be 3.64-18 times and 2.31-6.56 times respectively of a plain square.

Guo and co-authors (Guo et al., 2011) carried out a comparative study between center-cleared tape inserts and short width inserts in laminar zone employing numerical technique. It was reported that the thermal performance factor of center-cleared tape inserts can be improved by 7 to 20%. Moreover, they noted that tubes with short width inserts are weakened vis-à-vis typical twisted tape inserts. Other research work about center-cleared twisted tape can be found elsewhere (Nanan et al., 2013., Bhattacharyya et al., 2013., Bhattacharyya et al., 2012., Pal and Saha, 2014., Saha,2012., Nanan et al, 2014).

3.6 Effect of Tape with Different Types of Alterations

Few researchers (Eiamsa-ard et al., 2014., Eiamsa-ard et al., 2013., Murugesan et al., 2010., Arment et al., 2013., Ferroni et al., 2011., Hong et al., 2007., Singh et al., 2016.) also investigated specially designed twisted tape inserts or twisted tape fitted with different kinds of fixtures such as a metal nail. Eiasma-ard et al. (Eiamsa-ard et al., 2013) evaluated tubes equipped with twisted tape inserts and circular rings to assess the thermo-hydraulics of turbulent flow. The values of η, f and Nu were noted to be significantly improved for combined circular ring-twisted tape set-up than for CRT alone. The enhancement in the values of η, f and Nu were reported to be 6.3%, 82.8% and 25.8% respectively, vis-à-vis CRT alone. They found a vital dissipation in dynamic pressure on account of flow restriction by circular ring and tape inserts. Moreover, enhancement in flow contact area and generation of reverse and swirl flow due to circular ring and inserts were also reported as the reason for reduction in dynamic pressure. Murugesan et al. (Murugesan et al., 2010) evaluated the tubes with twisted tape inserts equipped with wire nails (WN). The attached wire nail was found to induce vortex flow which in turn enhanced the rate of heat transfer.

4. IMPACT OF THE COMBINATION OF TWISTED TAPE INSERTS WITH NANOFLUID

Recently, many researchers (Zarringhalam et al., 2016., Yu and Liu, 2013., Wongcharee and Eiamsa-ard, 2017., Wadekar, 2017., Tu et al., 2012., Sundar et al., 2016., Song et al., 2013., Chougule and Sahu, 2015.) have employed different nanofluids along with twisted tape inserts in diverse heat exchangers to enhance desirable parameters such as heat transfer rate and thermal performance efficiency. Some major studies of the influence of twisted tape inserts in the presence of nanofluid are summarized in table 3.

Sundar and co-authors (sundar et al., 2016) and Sharma and co-authors (Sharma et al., 2009) investigated h and f for transitional nanofluid flow inside a circular tube equipped with twisted tape inserts. They reported an enhancement of 23.69% and 44.71% respectively, vis-à-vis employing nanofluid and twisted tape and, twisted tape alone, in the rate of heat transfer at Reynolds Number 9000. Furthermore, they noted an increase of 1.21 times in the value of f while using 0.1% nanoparticle volume fraction with tape inserts as compared to pure water in plain tube. Sundar et al. (Sundar et al., 2012)

assessed the turbulent flow and thermal fields for a combination of magnetic nanofluid and full length tape inserts, in a pipe. They demonstrated an increase of 30.96% in heat transfer rate using the nanofluid (volume fraction - 0.6%) at Reynolds Number 22000, with respect to plain tube. On the other hand, an enhancement of 18.49% in heat transfer rate and 1.122% in friction factor was noted employing full length twisted tape w.r.t. plain tube.

Hosseinzhad and co-workers (Hosseinzhad et al., 2018) studied the turbulence in flow using twin twisted tapes along with nanofluid in a tubular heat exchanger via numerical pathway. They investigated co-swirl and counter-swirl flows. They found a direct relation of increase in heat transfer with the nanoparticle concentration and inverse relation with the twist ratio. The performance evaluation criterion was reported to be considerably higher in counter-swirl flow as compared to co-swirl flow. Khoshvaght et al. (Khoshvaght and Eskandari, 2015) investigated the influence of twist length on heat transfer enhancement in the presence of nanofluid. They took twisted tape inserts with different lengths such as uniform, low to high, high to low, low to high to low and high to low to high. They reported a vital impact of twist lengths on thermo-hydraulic attributes with ‘low to high’ twist length having the best characteristics.

In general, it was found that the heat transfer enhancement was better at outlet of the tube while employing twisted tape inserts with nanofluids on account of the impact of swirl flow; better in the sense that the performance of the device can be improved without enhancing the heat exchanger’s size. Moreover, it was noted that a combination of thicker tape inserts with nanofluid has better heat transfer η vis-à-vis thinner inserts. Furthermore, the twisted tapes with alternate axes were found to have superior thermal η w.r.t. conventional inserts.

5. DISCUSSIONS

Twisted tape inserts have been found as one of the most useful techniques in passive method. Many investigators have studied the influence of TT experimentally and numerically on the performance of heat exchangers. This paper discusses the impact of TT of diverse configurations, with and without nanofluids. TT enhances convective fluid transfer vis-à-vis plain tube on account of swirl flow generation. The combined effect of TT insert with nanofluid further increases the heat transfer and conveys even better results when thicker tape is employed with nanofluid.

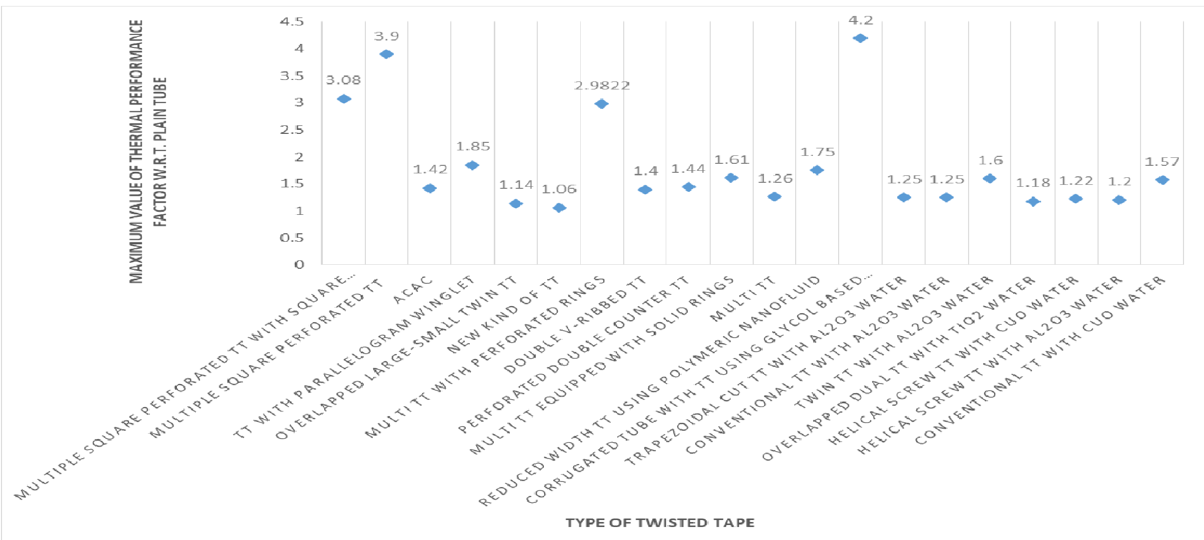


Figure 5: A Graph Reflecting the Effects of Various TT Configuration and Nanofluid on Thermal Performance Factor (0.5 ≤ TR ≤ 7.0).

A graph is plotted between the types of TT configurations and the maximum values of η(w.r.t plain tube) where all the studies took place at TR ranging from 0.5 to 7, as shown in figure 5. It may be noted that the maximum value of η among all the studies reviewed is found to be 4.2 in a corrugated tube equipped with TT in the presence of Al_2O_3/EG nanofluid at TR = 2 and φ = 0.5%. It is on account of synergetic effect of nanofluid along with high swirling due to low TR. On the other hand, the minimum value of η is found to be 1.06 in a new kind of TT insert where the length of TT was a quarter of the tube length. It is because of the fact that heat transfer is directly proportional to the length of the TT. Consequently, when the length is reduced, the heat transfer is reduced, which in turn reduces the Nu and η.

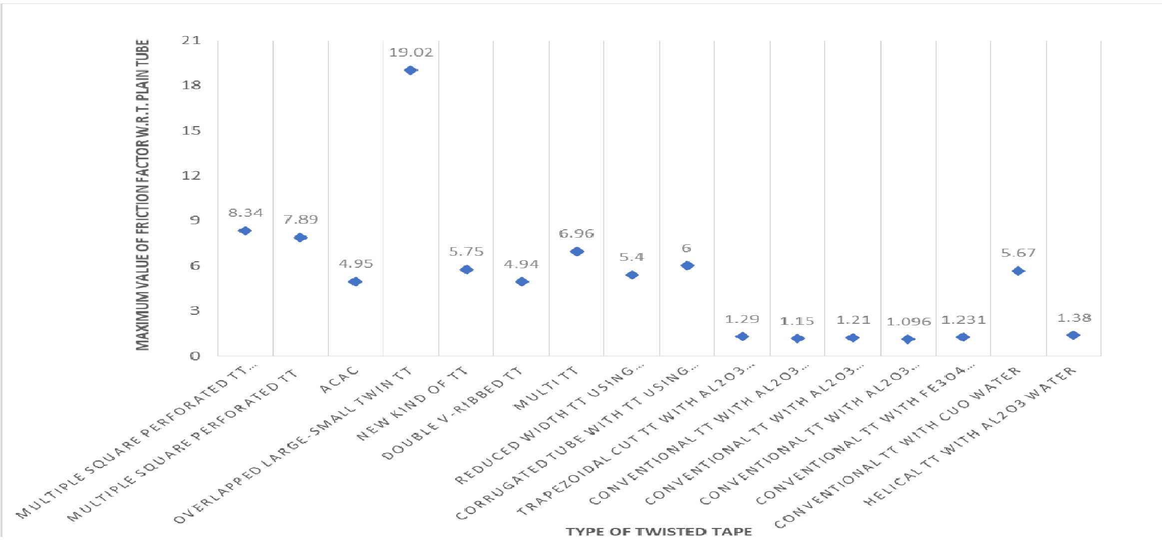


Figure 6: A Graph Reflecting the Effects of Various TT Configuration and Nanofluid on Friction Factor (0.5 ≤ TR ≤ 7.0).

Figure 6 is drawn between the types of TT configurations and the maximum values of friction factor vis-à-vis plain tube for all the reviewed research work. It is found that the maximum increase in f is 19.02 times of the plain tube, when spiral grooved tube equipped with twin overlapped TT in counter large/small combinations. The flow is turbulent in nature. The high value of f can be explained on the basis of configuration adopted in the study. Overlapped tapes are used in large and small combinations, which create uneven turbulence. In addition, the overlap feature is responsible for increase in contact area, which in turn enhances the friction factor. The minimum value of f is found as 1.15 in conventional tape inserts in the presence of Al_2O_3 water (φ = 0.03%) at TR = 5 and the flow is in turbulent region (Re = 3000). It is a plain tube with conventional TT and therefore, the frictional losses are low unlike U-cut, V-cut or grooved shaped inserts and corrugated or spiral tubes.

6. CONCLUSIONS AND RECOMMENDATIONS

This article sheds light on different types of twisted tape inserts in double pipe heat exchangers with diverse kind of nanofluids with and without nanofluid. The impact of tape inserts on thermal performance factor, Nusselt Number, friction factor and rate of heat transfer were discussed in a holistic manner. It was observed that, in general, the employment of TT enhances Nu, f, η and heat transfer rate vis-à-vis plain tube. Specific conclusions with recommendations are mentioned as under:

- Nu, f and η were found to increase with enhancing tape length. In addition, the maximum values of these parameters were recorded at full length of the inserts.

- It was found that an increase in the number of tapes increases the values of Nu, f and η; keeping all other parameters same.
- Multiple short length TT gave lesser pressure drop as compared to full length TT, for same TR.
- It was found that convective heat transfer coefficient and pressure drop improves when short length TT was introduced in the beginning of the tube.
- Application of twisted tape inserts was demonstrated to be more useful in laminar flows w.r.t. turbulent flows. On the contrary, when solid nanoparticles were employed with a high value of φ, heat transfer rate was better in turbulent flows than in laminar flows.
- Heat transfer rate was reported to improve with increasing width of TT and volume fraction of nanofluid in laminar flow.
- In case of a porous tape insert, Nu, f and η were found to have an inverse relationship with the porosity of TT.
- Nu and f were found to improve with decreasing TR and WR and increasing DR in the tube with cut TT inserts. On the other hand, heat transfer rate decreased with increase in width of the inserts and TR. The same was found to be true in the tape inserts with nanofluid where an enhanced heat transfer was recorded at lower TR. In general, η was found to have an inverse relation with Re.
- An improvement in the rate of heat transfer was noticed with decreasing diameter of the nanoparticles.
- When TT inserts are employed in the presence of nanofluid, Nu was found to increase while f was found to decrease with rise in Re.
- It should be noted that thermal performance factor should be the cardinal parameter while choosing a TT configuration.

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